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Spectral study on solar radio bursts in the microwave-millimeterwave transition

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Abstract : In order to evaluate the spectra of solar radio bursts in the microwave-millimeterwave transition region, the multifrequency burst data of Berne observatory have been used. The bursts give spectral nature which resemble inverted-U (IU), increasing (I), decreasing (D), U and Zigzag types. The spectral peak of these spectra occur at 11.8 GHz in most of the cases. The directivity and optical thickness of the absorbing layer above the source of bursts are determined. The results are discussed in light of the different emission and absorption mechanisms responsible for the generation of radio bursts.

Keywords : Spectra, solar bursts, microwave-millimeterwave region

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1. Introduction

Spectra of continuum type sporadic radio emission in different ranges of wavelength were investigated by various workers from time to time [1–4]. But recent thrust of research on solar radio burst spectral study encompasses mainly the millimeter wave band [5–9]. Millimeter-wavelength emission from solar flares has its great importance, as it acts as an alternative to the space-based gamma-ray observations. It is because, the emission in both millimeterwave and gamma-ray regions of the electromagnetic spectrum are closely linked with each other, as it is believed that the same population of electrons are responsible for both of these two kinds of emission [10,11]. But only large flares are accompanied by both millimeter and gamma-ray emission. As the large flares occur rarely in the solar atmosphere, the probability of getting millimetric burst data is not so high. So we have, in this present paper, analysed the spectra of solar radio bursts which occur simultaneously in a wide frequency band covering the microwave-millimeterwave transition region only. This study would help us to know the physical characteristics of the source region, as well as, to have an understanding about the process of emission in the said wavelength region.

2. Method of analysis

About 200 multifrequency bursts data which were available at least six of the observed frequencies 3.2, 5.2, 8.4, 10.4, 11.8, 19.6, 35 and 92.5 GHz by Berne observatory during the period 1980–1990 were collected from the Solar Geophysical Data bulletins issued by NOAA, USA. In each of the burst events, the peak fluxes in all the frequencies of observations occur generally at the same instant of time, and thus the spectra plotted for these events correspond to the real instantaneous spectra. The observed peak flux values at various frequencies of a particular burst event were normalised with respect to the greatest value of peak flux (where spectral peak occurs) observed for the same event. This procedure helps us to draw the spectra of different events in the same scale of the graph paper. The normalised spectra, thus obtained for 200 burst events, were roughly drawn for examining the spectral shape, as well as, for determining the spectral peaks. After inspecting all these

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spectra, the events giving similar nature of spectral shape were grouped together and the average spectra of different shapes were redrawn.

In this respect it is to be mentioned that in each of the burst-events the selected frequency emission in at least seven of the eight frequencies started generally within 2 min from each other. Moreover, in drawing the spectra, the data of a particular Radio observatory have only been considered in order to avoid the intrusion of error in the given flux densities due to the use of different time constants of receivers, to the differences or deficiencies of the calibration systems used by different observatories.

3. Results

Determination of spectral shape and peak .

The average spectra can be grouped into five categories, such as, Inverted–U (IU type), Intensity Decreasing with frequency (D type) and Increasing with frequency (I type), U and Zigzag types. It is examined that IU type of spectral nature predominates over other types, such as, D, I, U and Zigzag types. Out of these five types of spectra, the nature of three types of spectra which occurred large in number, are shown in Figure 1. All the spectra falling into the

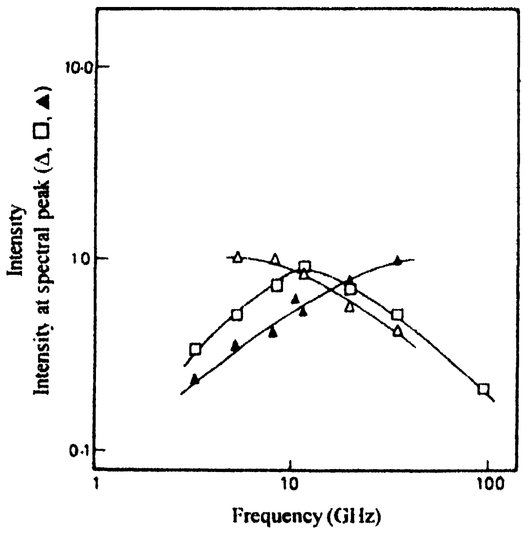

Figure 1. Average spectra in the microwave millimeterwave region. IU type □, I type ▲ and D type Δ.

category, such as, IU, and Zigzag types exhibit spectral peak around 11.8 GHz. But I and D types of spectra do not show any peak upto the frequency 92.5 GHz beyond which no observational data are available. The bursts showing U type of spectra give spectral minima in the vicinity of 11.8 GHz.

Determination of intensity distribution :

The occurrence frequency distribution or the intensity distribution of bursts is defined as

$$f(I_0) = \Delta N/\Delta I_0,$$

where ΔN gives the number of bursts in the peak flux interval ΔI_0. In order to find out such distribution function the peak fluxes of the radio bursts are divided into some convenient ranges of peak flux values and the number of events in those adopted ranges are counted. After dividing the number of events by the respective intervals of peak flux, we get the function $f(I_0)$. This function is plotted against the mid values of the respective peak flux ranges as shown in Figure 2. The distribution function $f(I_0)$ is found to obey the following relationship :

$$f(I_0) \sim I_{0A} - 1.1 .$$

In this connection, it is to be mentioned that the occurrence of large bursts goes nearly as inverse of their flux density.

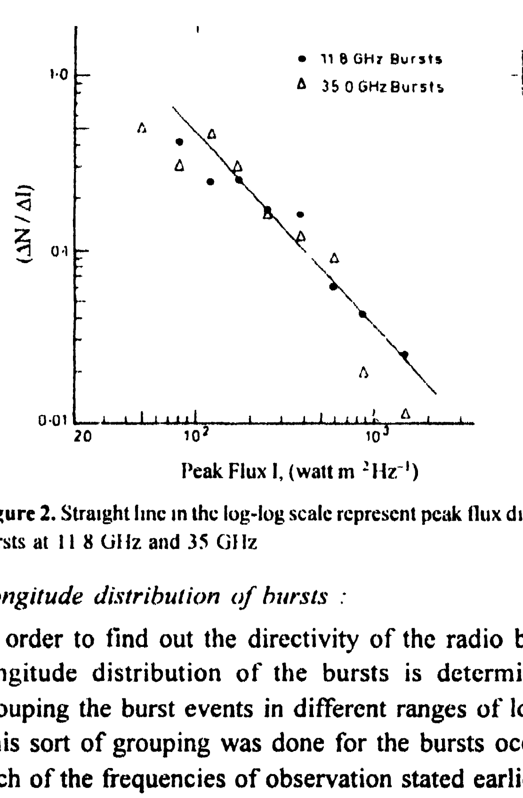

Figure 2. Straight line in the log-log scale represent peak flux distribution of bursts at 11 8 GHz and 35 GHz

Longitude distribution of bursts :

In order to find out the directivity of the radio bursts, the longitude distribution of the bursts is determined after grouping the burst events in different ranges of longitudes This sort of grouping was done for the bursts occurring at each of the frequencies of observation stated earlier. As the distribution is almost similar in nature at all the frequencies, we have presented in Table 1 the results for three frequencies covering the microwave-millimeterwave region.

Table 1. Longitude distribution of bursts

Longitude (θ) in degrees	$N(\theta)$ in % for the frequency		
	3.2 GHz	11.8 GHz	92.5 GHz
0–30°	42	41	40.8
31–60°	34	38	37 4
61–90°	24	21	21 8

Calculation of optical thickness :

Following Akabane's analysis [12], the directivity of bursts was determined from the Intensity distribution and longitude distribution of bursts. The optical thickness of the absorbing layer above the source region of a burst event is calculated after knowing the directivity which is regarded as due to attenuation caused by absorbing layer above the source of a burst. The values of optical thickness are examined to be the same (of the order of 0.6) in all the frequencies under consideration. This helps us to conclude that the radio sources have uniform characteristics with respect to optical thickness.

Prompt and delayed bursts :

The times of maximum intensity of 8.4 GHz and 35 GHz bursts are compared with those of 11.8 GHz. It is examined that in most of the cases, the times of maximum of 8.4 GHz bursts are behind (51% cases) that of 11.8 GHz, whereas, the times of maximum of 35 GHz bursts are ahead (56% cases) of that at 11.8 GHz [Figures 3(a) and 3(b)]. It is observed that the starting times of 8.4, 11.8 and 35 GHz bursts are the same in 80% cases [Figure 3(c) and 3(d)].

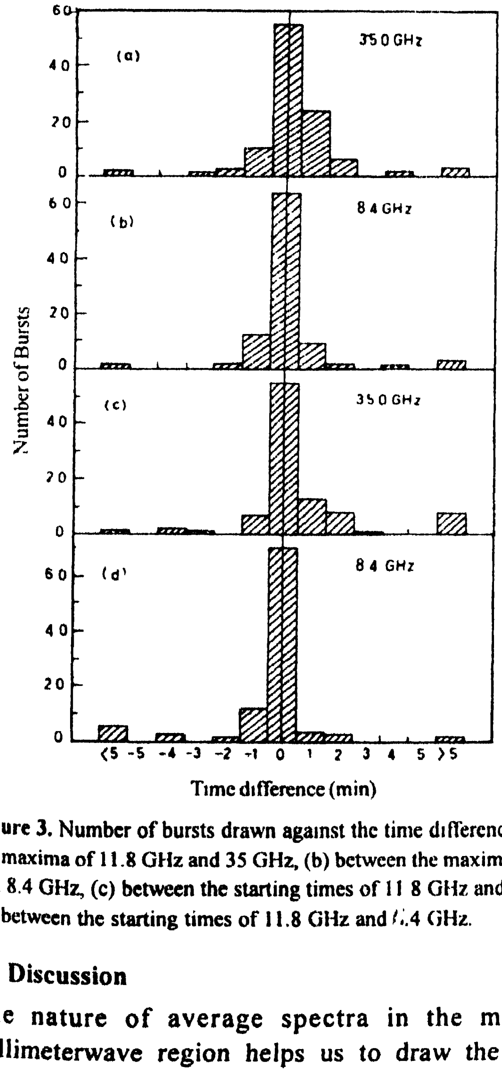

Figure 3. Number of bursts drawn against the time difference (a) between the maxima of 11.8 GHz and 35 GHz, (b) between the maxima of 11 8 GHz and 8.4 GHz, (c) between the starting times of 11 8 GHz and 35 GHz, and (d) between the starting times of 11.8 GHz and 8.4 GHz.

4. Discussion

The nature of average spectra in the microwave-millimeterwave region helps us to draw the following conclusions : (i) most of the bursts give spectral nature of Inverted U type with a peak around 11.8 GHz, (ii) the bursts under study have uniform characteristics in respect of their optical thickness, this holds good for the bursts at all the frequencies of observation, (iii) the times of maximum of lower frequency bursts are found to be behind that of 11.8 GHz bursts, whereas, the times of maxima of higher frequency bursts are ahead of that of 11.8 GHz bursts. Thus, the higher frequency radio bursts are prompt bursts, whereas, the lower frequency bursts may be treated as delayed bursts compared to that of 11.8 GHz.

As the values of optical thickness are nearly equal at different frequencies, it may be concluded that if this directivity is caused due to absorption, the height of the sources measured from the centre of the sun decreases with the increase of frequency. The differences in the times of maxima with respect to the 11.8 GHz bursts help us to conclude that there occurs an upward expansion of the source, as a result of which the effective height varies with frequency. Thus, millimetric burst are generated from a source region which lies in a deeper level of the solar atmosphere, whereas, the meter-decimeter bursts are developed in the upper atmosphere. But as a result of catastrophic explosion of flare, the energetic electrons are injected very quickly from the flare region into the 'trap' formed by the magnetic field of a sunspot where the radio emission takes place as a result of non thermal gyro-synchrotron (for subrelativistic particles) and synchrotron (for relativistic particles) mechanism undergoing in a magneto-active plasma [13–17]. Taking into consideration of these mechanisms, Takakura [18] calculated the magnetic field of the order of 400 G at 1.3×10^4 Km (effective height of 9.4 GHz radiation) and 100 G at 2.5×10^4 Km (effective height of 2 GHz radiation).

The shape of spectra in the millimeterwave region is found to be either decreasing or increasing in nature. For the IU types of spectra, the tail part which falls on the millimeterwave region, also exhibits decreasing in nature. These results comply with those of recent reports by some workers [19,20] who obtained almost spectral flattening throughout the bursts. These effects are interpreted as being a consequence of the hardening of the electron energy spectrum in the decay phase of bursts. As a most likely reason for such a hardening they consider coulomb collisions on energetic electrons continuously injected and trapped in a flaring loop.

References

[1] J P Castelli, J Aarons, G A Michael, C Jones and H C Ko *Solar Flares and Space Research* (Amsterdam : North Holland) (1969)

[2] D L Croom *Nature* **229** 142 (1971)

[3] M K Dasgupta, T K Das and S K Sarkar *Solar Phys* **67** 109 (1980)

[4] T K Das and M K Dasgupta *Indian J Radio Space Phys* **12** 68 (1983)

[5] D L Croom *Solar Phys* **15** 414 (1970)

[6] D L Croom *Proc Conf held at* Cumberland Lodge, Windsor, UK, (ed) M Rowanrobinson (1975)

[7] M R Kundu *Solar Phys* **21** 130 (1971)

[8] J M Payne *Rev Sci. Instrum (USA)* **59** 1911 (1988)

[9] R V Gorgutsa *Bull. Russ. Acad. Sci Phys. (USA)* **60** 1298 (1996)

[10] S M White and M R Kundu *Solar Phys.* **141** 347 (1992)

[11] M R Kundu *Rev. Radio Sci at the XXV-th General Assembly of International Union of Radio Science (URSI)* (Lille, France, August 28-September 5) (1996)

[12] K Akabane *Pub! Astron Soc Japan* **8** 173 (1956)

[13] T Takakura *Solar Phys* **1** 304 (1967)

[14] S S Holt and R Ramaty *Solar Phys.* **8** 119 (1969)

[15] R Ramaty *Astrophys. J.* **158** 753 (1969)

[16] R Ramaty *High Energy Phenomena on the Sun* (eds.) R Ramaty and P G Stone (NASA) **SP-342** p 188 (1973)

[17] R Ramaty and V Petrosian *Astrophys. J.* **178** 241 (1972)

[18] T Takakura *Solar Phys.* **26** 151 (1972)

[19] V F Melnikov and A Magun *Radiophys. Quantum Electron (USA)* **39** 971 (1996)

[20] V F Melnikov and A Magun *Sol Phys.* **178** 153 (1998)